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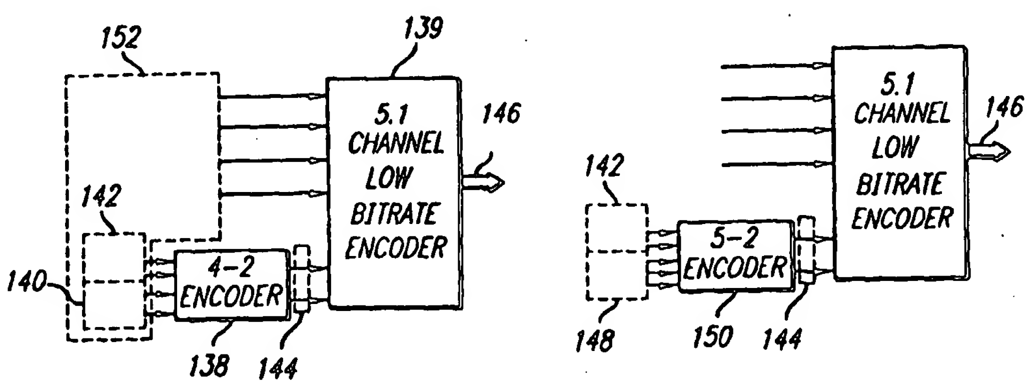
(54) Title: MULTI-CHANNEL AUDIO SURROUND SYSTEM



(57) Abstract

The present invention provides a technique for adding channels of sound to multi-channel digital audio recording format, including but not limited to 5.1 channel formats. The currently preferred embodiment is applied to surround channels, but can be extended to front or other channel configurations. Additional applications may include motion picture soundtracks, multi-channel music, digital television, home video, etc. Multiple layers of matrix encoders and decoders may be used to add, record, recover and reproduce additional channels of recorded sound. For example, an audio surround system according to the present invention may use a layer of matrix encoders in addition to the conventional compression layer to encode three or more channels of surround audio into the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system. Thus the three surround channels would be double compressed. A layer of matrix decoders in addition to the conventional decompression layer may be used to decode the three channels of surround audio from the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system.

MULTI-CHANNEL AUDIO SURROUND SYSTEM

Background of the Invention

1. Field of the Invention:

This invention relates to multi-channel audio systems, and more specifically to audio surround systems encoding and decoding 6.1 or more channels of surround audio.

2. Description of the Prior Art:

Today's state-of-the-art motion picture soundtracks are digitally recorded 5.1 channel formats. These 5.1 channels are recorded on the film area or on separate media synchronized with the film. Special digital coding techniques are used to maximize the recording quality for the available digital bit rate and transmission bandwidth.

Conventional 5.1 channels are generally reproduced as:

1) Three front channels produced by loudspeakers typically placed behind acoustically transmissive picture screens, to the left, right, and center of screen area. Said loudspeakers are typically single point source two-way or three-way full range systems.

2) Two surround channels typically placed along the left and right walls of the auditorium. Said surround channels are typically reproduced through arrays of loudspeakers in a horizontal line at a height above the audience.

3) A low frequency effects channel (L_{fe}, the 0.1 channel - 0.1 of the Bandwidth) reproduced by one or more loudspeakers generally referred to as "subwoofers" placed in the vicinity of the picture screen.

Most 5.1 channel recording/reproduction systems use three front channels for placement of sounds between the left and right edge of the picture screen as well as two surround channels placed to the left or right side of the audience

seating area. Some formats generate up to 7.1 channels and provide 2 additional front loudspeakers which are generally placed in "half-left" and "half-right" locations.

A limitation of conventional audio surround systems is the difficulty in placing sounds to the rear of the auditorium. To do so generally requires extra loudspeaker systems placed in the rear of the auditorium, fed by added signals recorded in the soundtrack.

Recording the extra surround channels can be achieved by digitally coding added tracks. This will involve an increase in bitrate bandwidth and place additional demands upon the scarce real-estate of the recording medium (film print or digital storage) In many cases the newly augmented channel recording schemes would require modifications of coding algorithms or re-assignment of recorded bit streams. This could lead to potential compatibility problems with existing coders and decoders already in the field, and potentially also to increasing costs of development and implementation.

What is needed is a technique if providing additional audio surround channels that is compatible with existing audio surround implementations and current recording media bandwidth limitations.

Summary of the Invention

The present invention provides a technique for adding channels of sound to multi-channel digital audio recording format, including but not limited to 5.1 channel formats. The currently preferred embodiment is applied to surround channels, but can be extended to front or other channel configurations. Additional applications may include motion picture soundtracks, multi-channel music, digital television, home video, etc.

In a first aspect of the present invention multiple layers of matrix encoders and decoders are used to add, record, recover and reproduce additional channels of recorded sound. For

example, an audio surround system according to the present invention may use a layer of matrix encoders in addition to the conventional compression layer to encode three or more channels of surround audio into the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system. Thus the three surround channels would be double compressed. A layer of matrix decoders in addition to the conventional decompression layer may be used to decode the three channels of surround audio from the two channels normally reserved for rear surround signals in a conventionally compressed 5.1 channel digital audio surround system.

In another aspect of the present invention, three or more audio channels that may be geographically or sonically close to each other may be exposed to multiple layers of compression and decompression to record and present 6.1 or more channels of surround audio using recording bandwidth of conventional 5.1 channel recording and recovery equipment.

In another aspect of the present invention 6.1 or more discrete channels of an audio program may be encoded and recorded to permit recovery of 5.1 or fewer channels of the audio program using conventional equipment.

These and other features and advantages of this invention will become further apparent from the detailed description and accompanying figures that follow. In the figures and description, numerals indicate the various features of the invention, like numerals referring to like features throughout both the drawings and the description.

Brief Description of the Drawings

Fig. 1 is a block diagram of a 6.1 channel audio surround system according to the present invention.

Fig. 2 is a is a block diagram of a conventional 5.1 channel audio surround system.

Fig. 3 is a diagram of a two parameter sound matrix.

Fig. 4 is a diagram of a 3-2 matrix encoder.

Fig. 5 is a diagram of a 2-3 matrix decoder.

Fig. 6 is a basic diagram of a 2-3 matrix decoder with crosstalk cancellation.

Fig. 7 is a detailed diagram of a 2-3 matrix decoder with dual detection crosstalk cancellation.

Fig. 8 is a simple block diagram of a 6.1 channel audio surround system according to the present invention.

Fig. 9 is a simple block diagram of a 7.1 channel audio encoder according to the present invention.

Fig. 10 is a simple block diagram of an 8.1 channel audio encoder according to the present invention.

Fig. 11 is a simple block diagram of an audio encoding and decoding system illustrating multiple signal lumping.

Fig. 12 is a simple block diagram of multi-phase encoding and illustrating phase signal separation.

Fig. 13 is a simple block diagram of a four input encoder with decorrelation.

Detailed Description of the Preferred Embodiment(s)

Referring to Fig. 1, multi-channel audio surround system 10 includes multi-channel encoding system 12 delivery means 14 and multi-channel decoding system 16. Multi-channel encoding system 12 includes encoder block 18 and sound converters 22-28. Sound sensors 22-28 may be conventional devices such as microphones or other interface to sound source or generation device 32 and may include signal processing capability. Encoder block 18 may also include signal processing capability such as block 30 which may include level adjustment as well as other signal processing

capability. In a currently preferred embodiment of the present invention encoder block 18 of multi-channel encoding system 12 is a mirror image of decoder block 20 of multi-channel decoding system 16 and may contain signal processing capability such as block 34, other configurations may also produce satisfactory results.

Sound information 36 encoded by encoder block 18 may be recorded as sound signal 38 on a recording means 14 such as Laser Disc 14A, CD 14B, DVD 14C, Film 14D, Magnetic Tape 14E, or other media 14F or may be delivered in a transmitted signal such as signal 14G. Signal 14G may be some form of electromagnetic radiation such as conventional broadcast or satellite signals or fiber optic light. Sound information 40 may be recovered from recording means 14 and passed to decoder block 20. Decoder block 20 may recover sound information 42 which corresponds to the original sound information 36. sound information 42 may be transformed to sounds 44-50 using any suitable device such as speakers 51-57.

An alternative to coding extra "discrete" channels is to encode additional channels into the existing tracks via matrixing schemes. Matrix encoding employs mathematical equations defining parameters for encoding transmission and decoding of a plurality of signals encoded through two or more transmitted tracks. The advantages of matrix approaches include simplicity, bandwidth efficiency, and compatibility with existing formats and playback sound systems.

Referring now to Fig. 3, one approach in multi-channel audio coding uses amplitude 58 and phase 60 as two parameters in the equations such as equation 66 describing output signals such as output signal 68. The relative amplitude and relative phase of signals 62 present in a plurality of audio tracks 64 can represent several channels 66 comprised within one or more audio tracks 64.

Matrixing schemes are often described by the denomination A-B-C were A represents the number of input channels, B represents the number of actual recorded and transmitted channels, and C represents the number of output channels present in the decode process. Thus, 3-2-3, 4-2-4, or 5-2-5, are some of the possible matrixing schemes possible using an amplitude-phase matrix approach such as illustrated in Fig. 3.

Fig.'s 4 and 5 show a basic 3-2-3 encoder/decoder system using encoder 78 and decoder 80 that could be used in conjunction with the sound system shown in Fig. 3. Referring now to Fig. 4, Sl, signal 76, and Sr may be the Surround Left, Surround Back, and Surround Right signals respectively. Slt and Srt may be the Surround Left Total and Surround Right Total signals respectively. In the simple 3-2 encoding signal 76 is reduced in level by 3 decibels in block 70 then added to Sl and Sr signals in adders 72 and 74 respectively to form the Slt and Srt. The 3 decibel attenuation to signal 76 afforded by block 70 preserves equal sound pressure levels for decoded and undecoded playback of the encoded signals Slt and Srt. Thus a program recorded according to the present invention may be decoded and presented using a conventional audio system with minimal interference from the unused encoded signal 76. In a currently preferred embodiment of the present invention Slt and Srt are recorded in the track locations of Sl and Sr respectively in a conventional 5.1 track sound format.

The .1 track represents a limited bandwidth low frequency effects channel that is treated as a discrete channel for encoding but only represents a fraction of the bandwidth required for other discrete channels. Hereinafter full frequency channels will be referred to using whole decimal numbers and a limited bandwidth channel will be referred to as .1. Thus a system having four full frequency channels and a limited bandwidth channel will be referred to as 4.1.

Referring now to Fig. 5, in decoder 80 Slt and Srt may be converted back to Sl, signal 76, and Sr through a summation of Slt and Srt in summer 82 to derive Sb, Sl and Sr. Signal 76 is again reduced in level by 3 decibels at block 84 in order to recover the original signal level of signal 76 applied to encoder 78.

The mathematical equations for the encode process of encoder 78 are:

$$Slt=Sl + 0.707(\text{signal } 76);$$
$$Srt=Sr + 0.707 \text{ signal } 76.$$

The mathematical equations for the decode process of decoder 80 are:

$$Sl=Slt;$$
$$\text{signal } 76 =0.707(Slt+Srt);$$
$$Sr=Srt.$$

Using a simple decoder such as decoder 80 the final separation between Sl, signal 76, and Sr may be only three decibels and may enable crosstalk to be detected. Referring now to Fig. 6, use of a crosstalk cancellation stage such as crosstalk cancellation block 86 as part of a decoder such as decoder 88 may be used to detect conditions of crosstalk in Sl_n, Rear signal 90_n and Sr_n and actively remove the crosstalk signals from the offended channels such as in Sl, Rear signal 90 and Sr.

Referring now to Fig. 7, crosstalk cancellation decoder such as crosstalk cancellation decoder 92 may include a duel detection network such as network 94 measuring Slt/Srt in stage 96 and measuring Slt+Srt/Slt-Srt in stage 98. The result of the measurements of stages 96 and 98 may be used to controls voltage controlled amplifiers (VCA's) such as VCA 100 or equivalent schemes, injecting subtractive crosstalk signals such as signals 102, 104 and 106 to the three output signals 108, 110 and 112 respectively. The resulting separation of output signals such

as output signals 108, 110 and 112 may be in excess of 20 decibels, and, through careful selection of the network time constant Tc the action of the crosstalk cancellation scheme can be made inaudible to listeners.

Application to Film Soundtracks

Referring now to Fig. 8, the matrix techniques and 3-2-3 schemes described Fig.'s 3-7 may be applied to a conventional audio surround system such as a 5.1 channel digital encoding/recording device such as device 114 and a 5.1 channel digital playback device such as device 116 to achieve a 6.1 channel format such as format 118 incorporating 6.1 discrete channels such as channels 122 and resulting in a full 6.1 channel reproduction such as signals 120. Left channel 122l, Center channel 122c, Right channel 122r and LFE (Low Frequency Effects) channel 122x are fed directly into a 5.1 channel digital encoding/recording device such as device 114. Surround signals such as Side Left channel 126, Rear channel 124, and Side Right channel 128 are first fed into an encoder such as matrix encoder 130. Output 132 of matrix encoder 130 may then be fed into conventional Surround Left and Surround Right inputs 134 and 136 respectively. Upon Playback the inverse order of operations may be used to extract 6.1 channels 120.

Referring now to Fig.'s 9 and 10, multi-layer sound encoding according to the present invention may be applied to encode and decode 7.1 and 8.1 discrete channels of surround audio. Additional channels 140 or 148 may first be encoded with two conventional channels of input sound such as channels 142, via a first layer matrix encoder such as encoder 136 or 150 respectively. Output 144 of which may be recorded or otherwise preserved using some media 146 such as on track Sl and track Sr of a film soundtrack. To decode and playback program 152 the inverse order of operations 138 and 139 may be used to extract program 152, similarly for Fig. 10.

This invention may also be applied to any conventional audio surround system such as 7.1 channel formats, although the text mainly makes reference to 5.1 formats, which are in more common use.

Referring now to Fig. 11, a side-effect of matrixing can be unwanted "lumping" or combining of multiple signals into one channel. Typically two equal signals such as signals 154 and 156 placed in two channels such as Sl and Sr separated by one intermediate channel such as rear channel 158 may sum into the intermediate channel resulting in large signal 160. In this condition Sl=Sr and rear channel 158=0, so in an encoder such as encoder 162 where Slt=Sl+0.707(rear channel 158)=Sl and Srt=Sr+0.707(rear channel 158)=Sr. Therefore Slt=Srt. In a decoder such as decoder 164, Sl=Slt and Sr=Srt and rear channel 158=0.707(Slt+Srt) assuming no crosstalk cancellation.

If crosstalk cancellation is present, and Slt=Srt, a crosstalk cancellation detector analysis may detect applied signals 166 as being of the condition Slt/Srt=1 and Slt+Srt/Slt-Srt=max. Thus crosstalk cancellation present in decoder 164 will thus add crosstalk signals to Sl and Sr that are the opposite cardinal point of the offending signals, and after the crosstalk cancellation subtractive stage the outputs will be: Sl=Slt-Srt=0; Sr=Srt-Slt=0; Sb=0.707 (Slt+Srt)=1.414Slt=1.414Srt. Output 168 may be characterized as only a Rear signal such as large signal 160 at the output of the Encode/Decoder process, when equal signals were originally placed into Side Left and Side Right inputs.

Referring now to Fig. 12, a solution to this "lumping" issue is to add a function such as blocks 170 and 174 in encoder 172 to selectively alter the phase relationships between two equal signals such as signals 176 and 178. This would result in the two signals being reproduced at output 180 as spread out over the three adjacent channels such as channels 181-183

instead of lumping into channel 182 as demonstrated in Fig. 11. A crosstalk cancellation scheme such as discussed in Fig. 7 would not activate since no clear cardinal amplitude or phase relationships exist between the Slt and Srt signals. Cardinal points would have been one of the below conditions: Slt=Srt, or Slt=-Srt, or Slt=1 and Srt=0, or Slt=0 and Srt=1.

There are several possible means for altering the phase relationships as mentioned here. These include All-Pass filter networks, Hilbert Transform functions, Time-domain signal distribution, and pitch shifting. Such schemes have been referred to as Decorrelation in the Holman Patent 5,043,970.

A 3-2-3 encoder/decoder block diagram as shown in Fig. 12 presents a three input solution. Signals placed equally in inputs Side-Left and Side-Right would have their relative phase altered and would thus be decoded as spread across S-L, Rear, and S-R.

Referring now to Fig. 13, a 4-2 encoder block diagram with 4 inputs 184 is shown. Signals such as signals 185-187 applied to inputs Sl, Rear or Sr would be encoded and decoded as appropriate. A signal such as signal 188 applied to a Surround-All input such as input 190 would be decoded as spread across the outputs 192.

Other applications of the Invention:

Multichannel Digital Film Soundtracks transferred to Home Video media, such as DVD 14c (Digital Versatile Disc) or Laserdisc 14a with Dolby Digital track, can benefit from this invention. The listener at home would simply need a matrix decoding device such as multi-channel decoding system 16, either as an add-on to an existing multichannel surround sound system, or built-in to a new Surround sound processor, in order to extract the additional channels. Similarly, broadcast media 146

with multichannel digital sound, such as Direct Satellite (DSS) or the new Digital TV standard, can benefit from the invention.

Multichannel music, recorded onto 5.1 channel formats can also benefit from the invention through added encoded channels to be decoded in the home, much the same way as for audio-visual media.

Having now described the invention in accordance with the requirements of the patent statutes, those skilled in this art will understand how to make changes and modifications in the present invention to meet their specific requirements or conditions. Such changes and modifications may be made without departing from the scope and spirit of the invention as set forth in the following claims.

I claim:

1. A multi-channel audio system, comprising:

a secondary encoding means for encoding three or more secondary signals into two or more secondary channels;

a primary encoding means for encoding 3.1 or more primary signals and said two or more secondary channels together into a total encoded program signal;

means for recording said total encoded program signal as a recorded signal;

a primary decoder means for decoding said recorded signal into 3.1 or more primary output signals and two or more secondary channels; and

a secondary decoder means for decoding said two or more secondary channels into three or more secondary output signals.

2. A multi-channel audio encoding system, comprising:

a secondary encoding means for encoding three or more secondary signals into two or more secondary channels; and

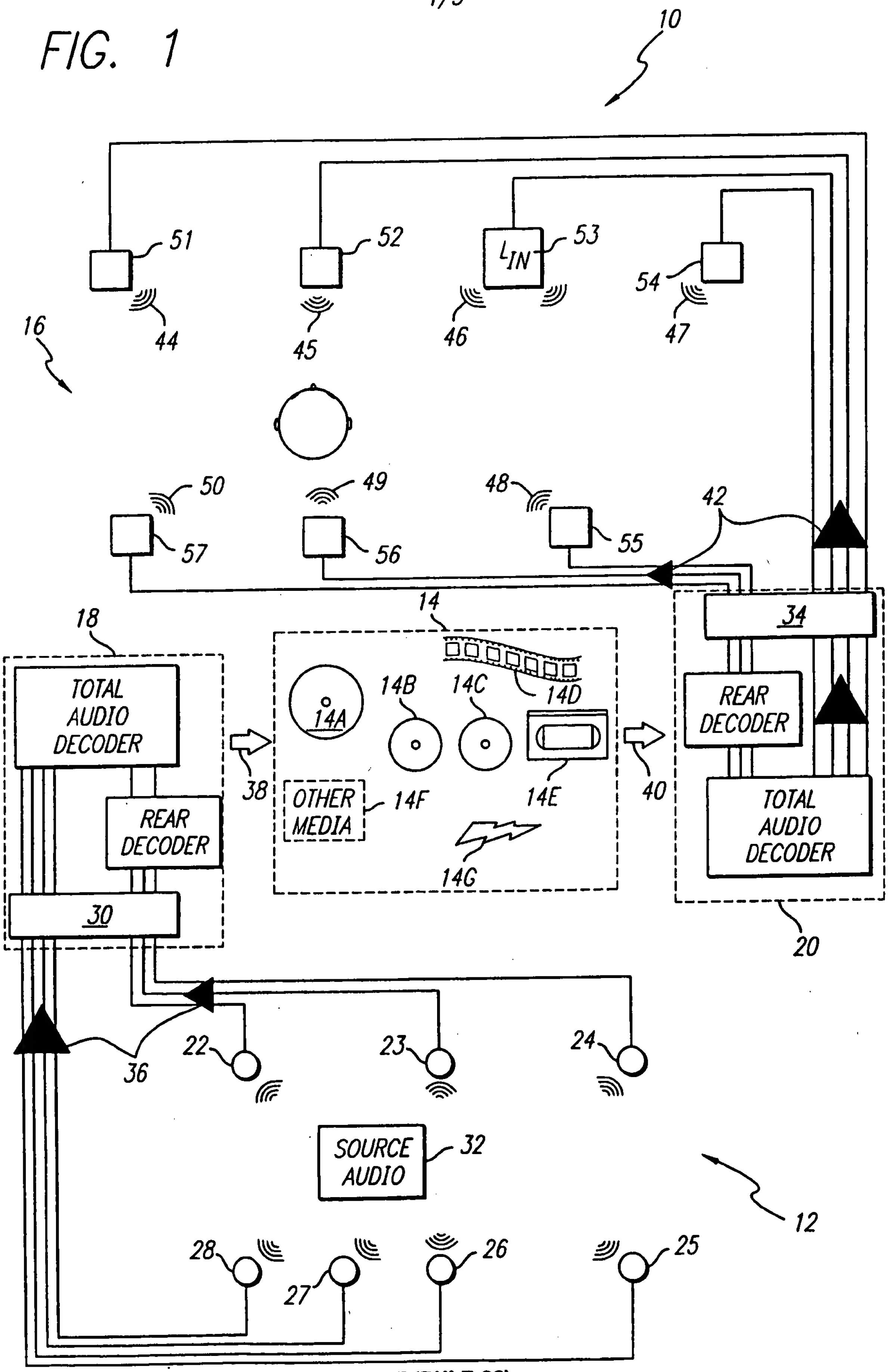
a primary encoding means for encoding 3.1 or more primary signals and said two or more secondary channels together into a total encoded program signal.

3. A multi-channel audio decoding system, comprising:

a primary decoder means for decoding a multi-channel audio signal into 3.1 or more primary output signals and two secondary channels; and

a secondary decoder means for decoding said two secondary channels into three or more secondary output signals.

FIG. 1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OTHER MEDIA
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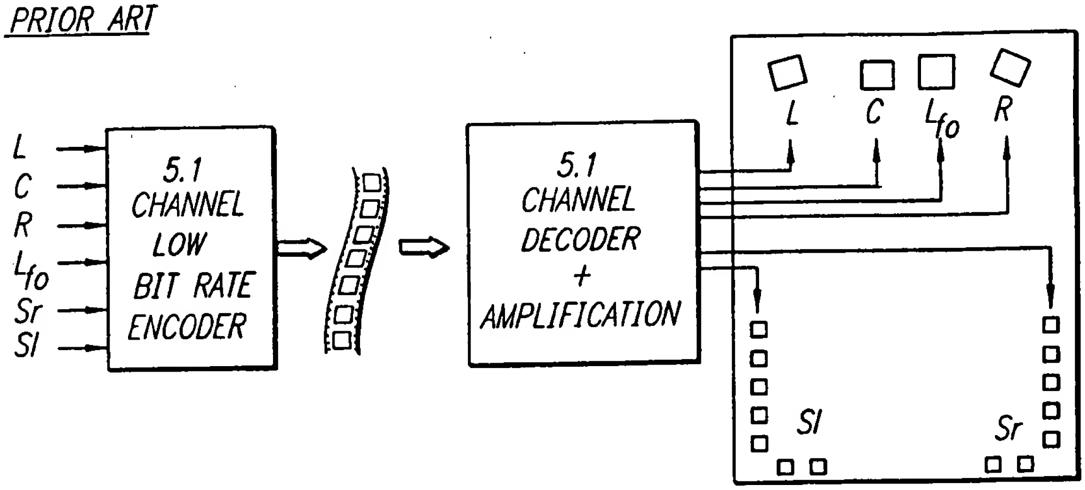
FIG. 2

PRIOR ART



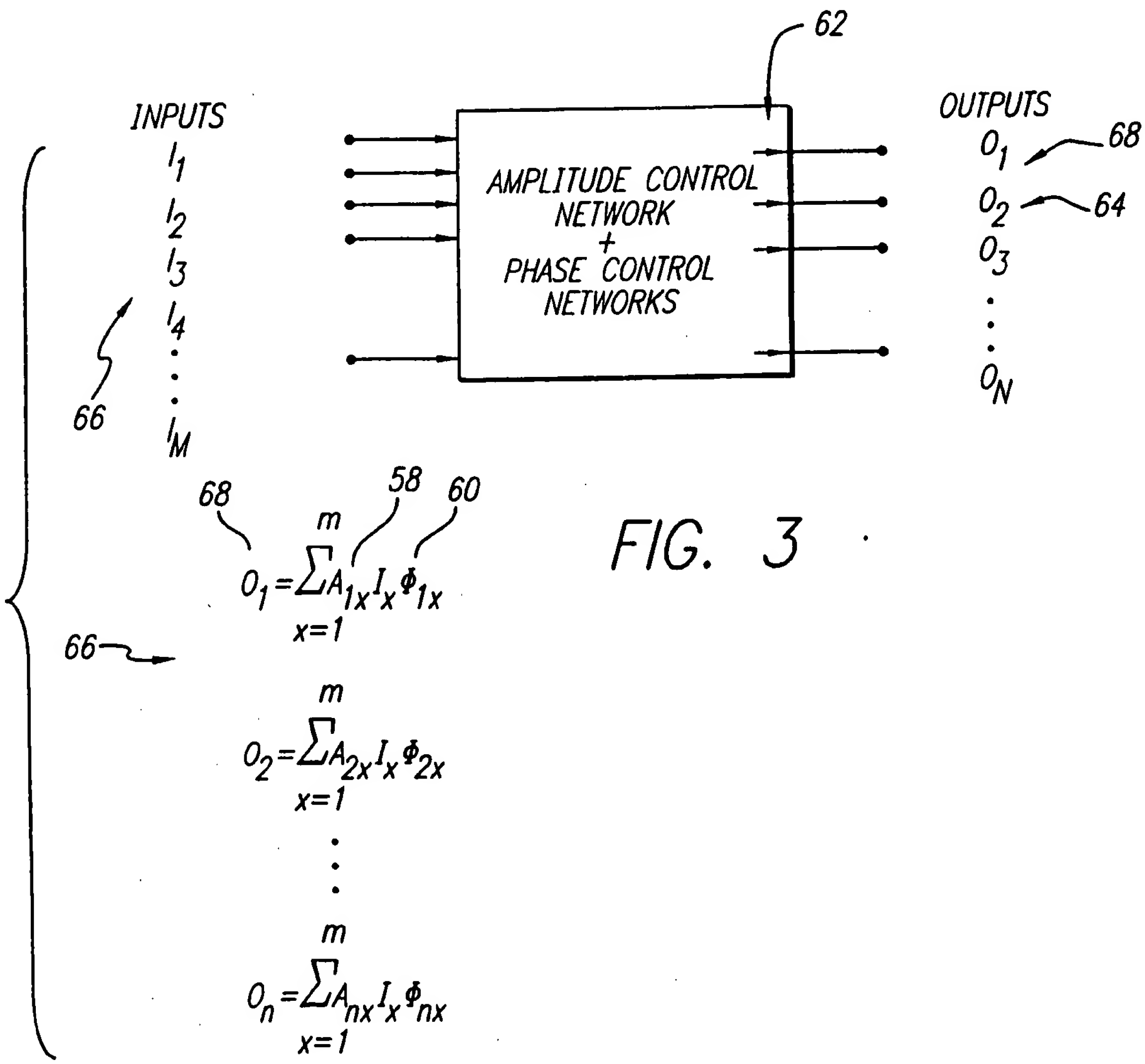


FIG. 3

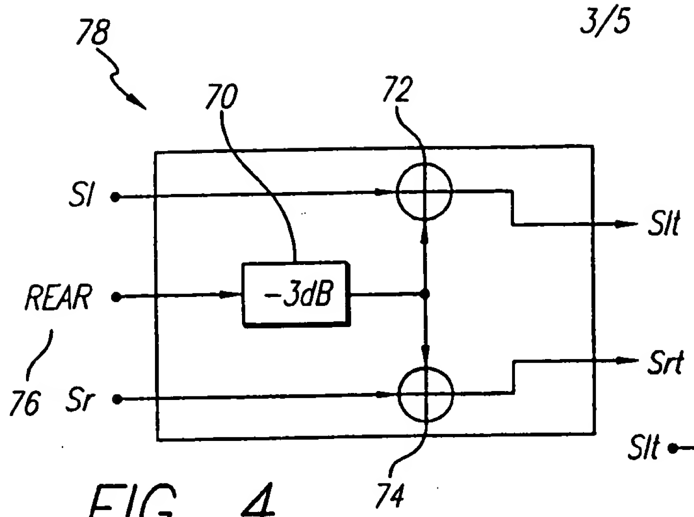


FIG. 4
PRIOR ART

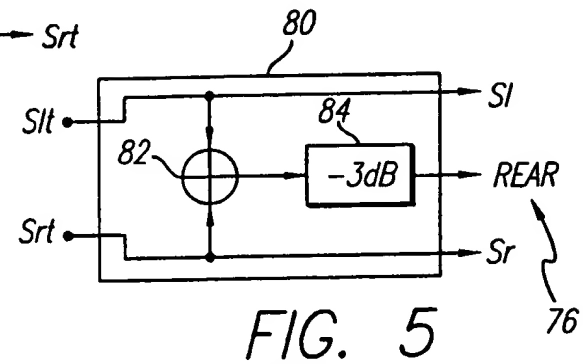


FIG. 5
PRIOR ART

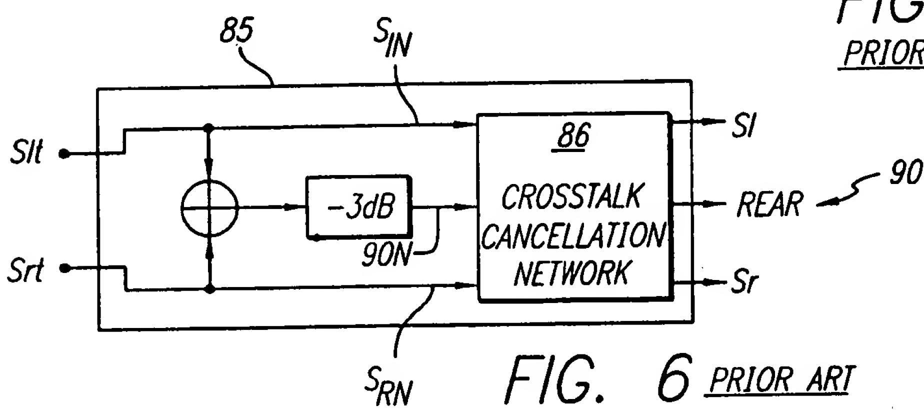


FIG. 6 PRIOR ART

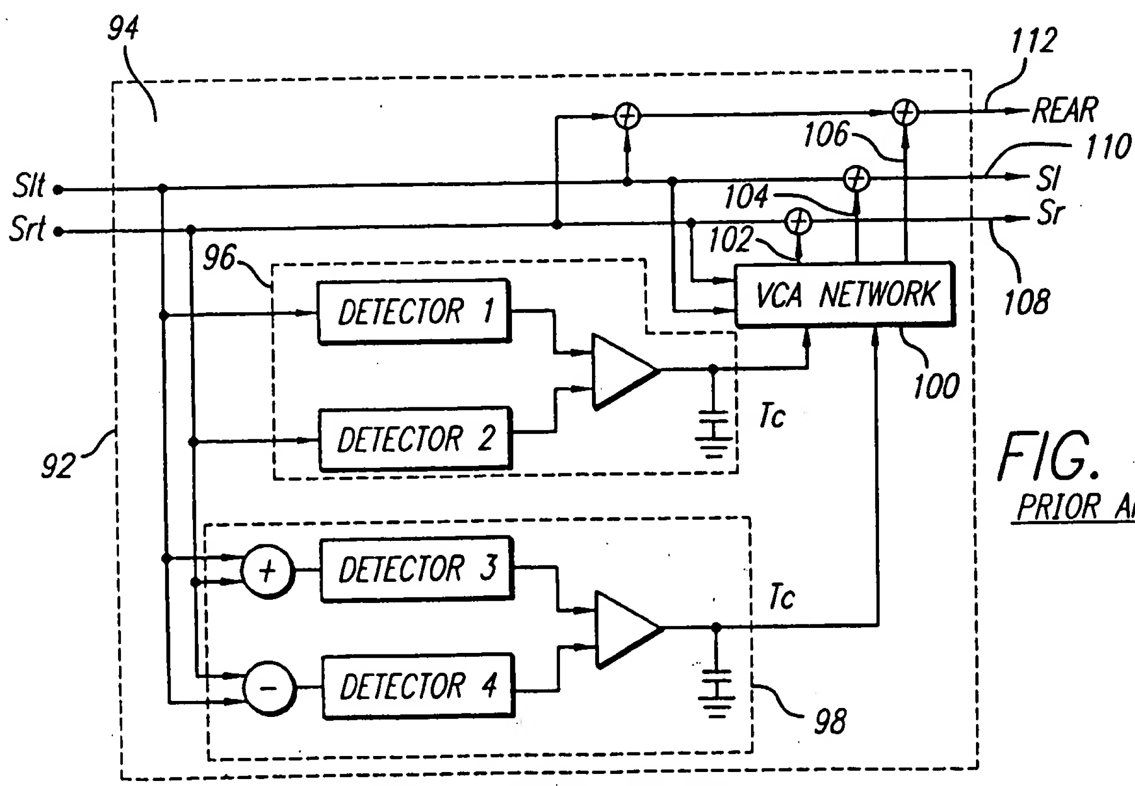


FIG. 7
PRIOR ART

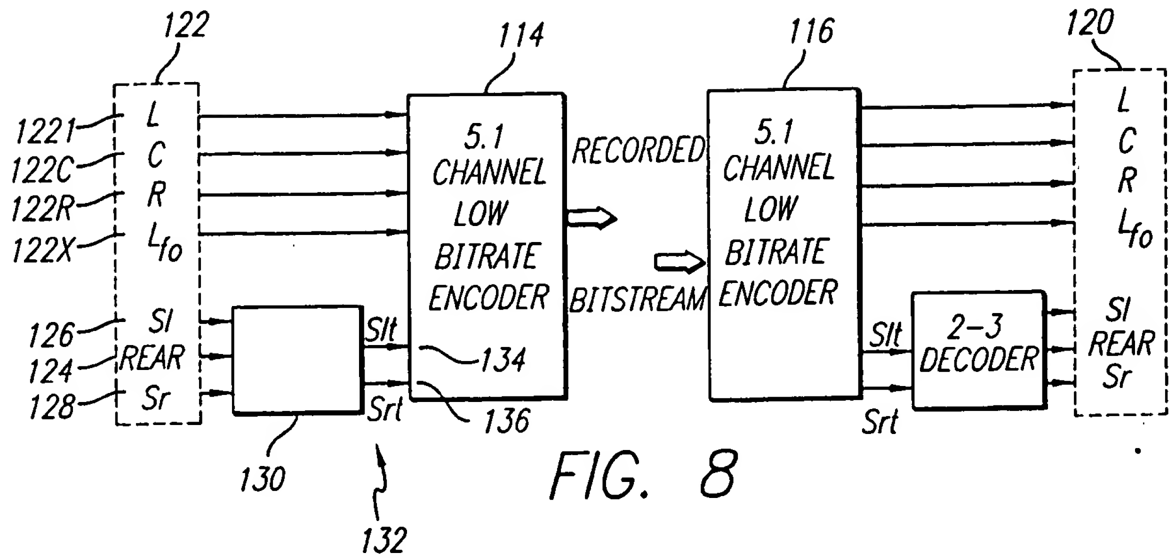


FIG. 8

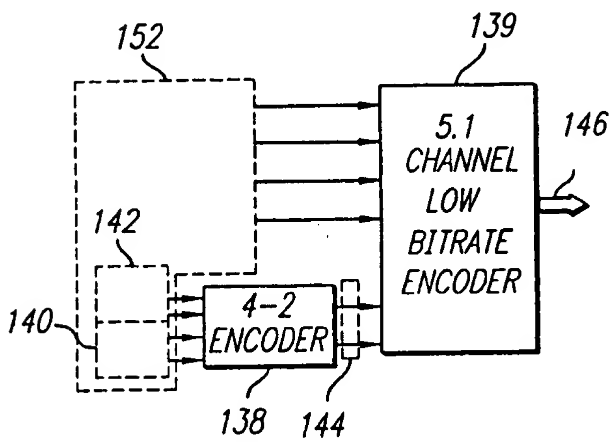


FIG. 9

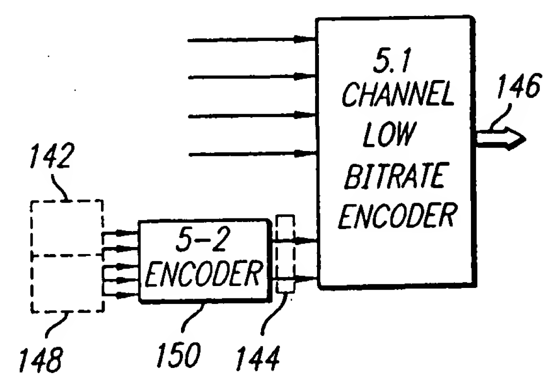


FIG. 10

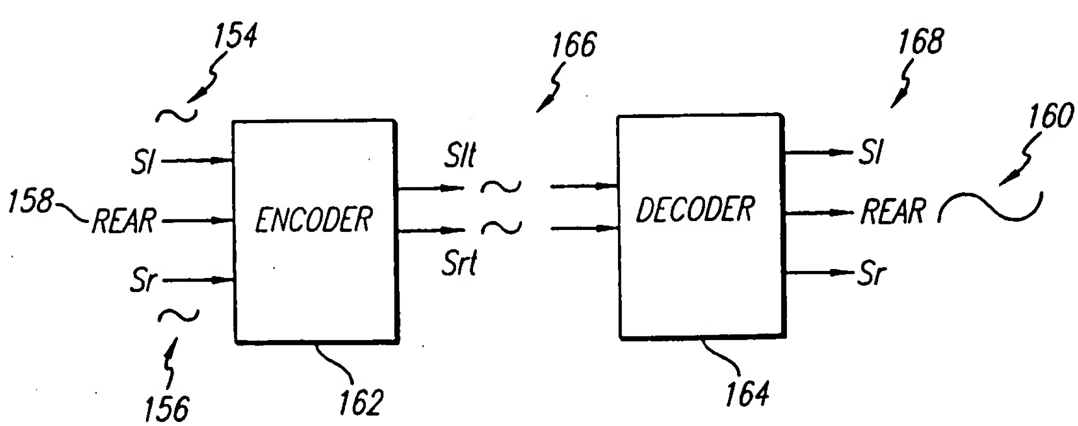
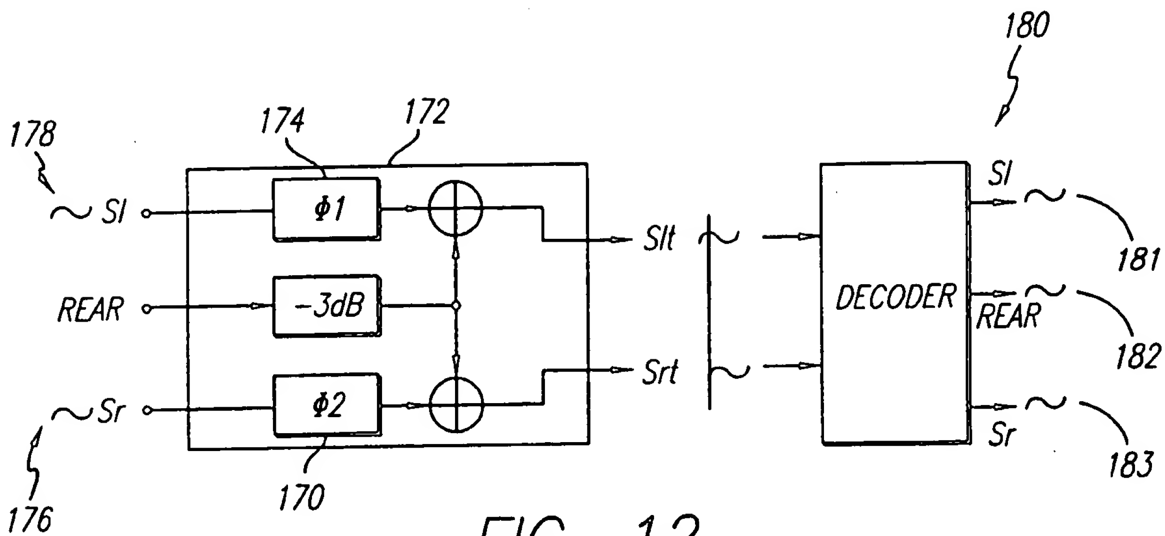


FIG. 11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Φ1
SIt
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REAR
−3dB
REAR
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Sr
Φ2
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Sr
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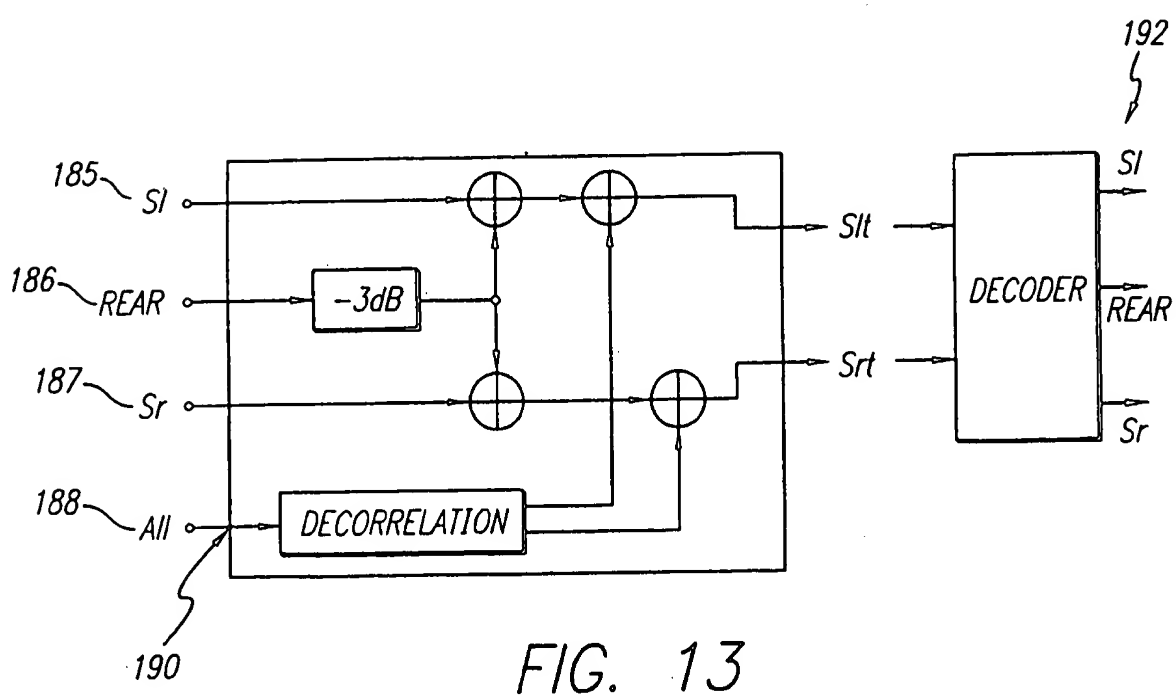
176
170

FIG. 12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185
SI
SI
SIt
DECODER
186
REAR
−3dB
REAR
187
Sr
Srt
Sr
188
All
DECORRELATION
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FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/16213

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04S3/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 5 701 346 A (HERRE ET AL.) 23 December 1997 (1997-12-23) column 1, line 6-13 column 2, line 23-59 column 3, line 32-59 column 4, line 33 -column 7, line 2 ---	1-3
A	EP 0 119 101 A (DOLBY LABORATORIES) 19 September 1984 (1984-09-19) page 17, line 21 -page 22, line 11 --- -/--	1-3

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 December 1999	12/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Zanti, P

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

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